12. Properties of Swords

12.1 The Basics

12.1.1 Sword Performance

How a Swordsman Looks at Sword Performance

What defines the **quality of sword**? If we consider its fighting value and not its prestige value, it can only be its performance in a sword fight with another sword bearer. Swords for showing off or for hacking defenseless people into pieces need not to be particularly good and thus are of no interest here.
John Clements, an experienced swordsman, made a list[1)] for essential **swords properties**, here are the major points:

- Cutting Ability
- Thrusting Ability
- Guarding Capacity
- Speed
- Technical Versatility
- Durability

John discusses these points by comparing a Japanese katana and a medieval longsword. Let's look at his points one by one, to some extent in John's own words.

- **Cutting ability**: This is the blade's capacity to deliver powerful shearing and cleaving edge blows. The katana, with its living tradition of practice, is well known for demonstrating its cutting power. Its single, hardened, wedge-like edge has long been shown to be capable of extraordinary sharpness.
  The longsword, has not acquired a similar reputation. It is certain that both weapons successfully faced opponents wearing soft and hard armors without great difficulty. Nonetheless, a curved blade is mechanically superior to a straight one at delivering edge blows to produce injury. And due to its hardness, the single curving edge of the katana is very good at penetrating even hard materials with straight-on strikes. Verdict: Katana.
  I wonder why John does not consider wootz blades, also famous for extreme sharpness and cutting power. From a metallurgical point of view, you don't just want a sharp edge, you want it to stay sharp when you hit something, and you want it not to break. That calls first for a hard material, and second for a material with the ability to disperse a considerable amount of energy released in a small area / volume without fracture or much deformation. That necessitates a large "fracture toughness" and thus a material that is first uniform and free from small defects like microcracks or micro-inclusions and, second, somewhat deformable or ductile and not completely brittle. No steel offers both properties equally well, so for cutting ability alone you tend to go in the "ultrahard but somewhat brittle" direction, i.e. for a katana.
- **Thrusting ability**: This is the capacity for a weapon to make penetrating stabs with its point. Whether against armored or unarmored opponents, a thrust has long been recognized as more difficult to defend against, easier to deliver a fatal wound with, and quicker and farther reaching than a cut. As has been known since ancient times, the geometry of a straight weapon means its thrust hits more quickly and deceptively than does a curved or semi-curved one. Verdict: Longsword.
- **Guarding capacity**: This is the weapon's ability to be moved to ward, parry, and block the assorted strikes of other weapons it had to face in combat. Its design affects the physical mechanics of how the object can be wielded defensively and the resilience and toughness of the blade is a component in this. All things being equal, the inherent defensive potential then comes down to the tool's geometry, or shape. Verdict: Longsword.
  Much of what John relates here (and I have considerably shortened it) also applies to the 4th point "speed".
- **Speed**: Speed is the velocity at which any hand-weapon can perform defensive and offensive actions to deliver hits or impede blows. The quickness of a hand-weapon depends partially upon the user's own prowess, as the weapon itself does not move, the swordsman moves it. Since the relative weights of both sword types are nearly equal, the issue comes down to the geometry of how each can be moved. A shorter curved blade can slash more quickly, but a longer, narrower, straight blade can certainly thrust more quickly. The slashing cut of a shorter curved weapon wielded in strong fluid motion can be more maneuverable than the less oblique cuts of a longer straight blade similarly used. Verdict: Katana.
- **Technical Versatility**: This is the mechanical utility the weapon has for being employed in distinct offensive and defensive actions. Surely the most controversial category to rate any sword on is its fighting capacity. The katana is the extreme single-edged cutting performer while the longsword is an excellent multitasker. Both are capable of numerous slashing, slicing, and stabbing techniques. Both weapons utilize counter-striking and defensive displacements. However, straight double edges permit cutting along 16 different lines of attack compared to eight with a single-edged curved blade. Verdict: Longsword.

- **Durability**: Durability in a fighting sword refers to its general tenacity and its resilience and in delivering blows and receiving impacts over time without breaking or becoming bent. The more resistant to brittle catastrophic failure a sword blade is, however, the more malleable it becomes - meaning the easier a bend will set in.
  The katana required more rigidity for its hard-cutting design, while for its utility the longsword was more of a spring. The katana's edge leaned towards more brittleness while its spine was more prone to bending. In both weapons, cross sectional shape compensated for weaknesses while capitalizing on strengths. Flexibility, or the ability for a blade to deform but return true, though regularly exaggerated in modern times, was actually of very little concern for swords intended for serious combat, and does not enter into the criteria here.
  No sword is indestructible. All are produced as perishable tools with a certain expected working lifetime. Which blade historically could possibly be called the more durable in combat is then an exceptionally complex issue to address and perhaps unanswerable. Verdict: Unknown.

Those points are important for the user of a sword. However, they leave the materials scientist or even the maker of a sword somewhat puzzled. How can you *grade* these properties? That means you must produce a *number*, that comes from an objective measurement. How are you going to do this?
The answer is simple: you won't. The properties expressed in the key words above relate to many "technical" aspects of swords and to "properties" of the person wielding it and there is no way to measure those properties objectively without involving human opinion. A violinist will find a Stradivari or Guarneri violin far superior to "normal" ones but scientists cannot tell how the small differences they might find by making all kinds of measurements relate to the judgement of the experienced users.
My point there is that what counts is the judgment of the user. Nothing will convince him to use the "scientifically" superior sword if it doesn't feel right to him. And that's as it should be.

- However, since I'm not a user of swords, I only can give you the science point of view. Happily, we are in a somewhat better position than the musical instrument guys. Science will be able to come up with some points that do relate rather directly to the performance of a sword.
  So let's look at sword performance now from a scientific point of view. We will distinguish two very basic cases: static properties and dynamic properties. What follows is a general introduction of the meaning of those terms.

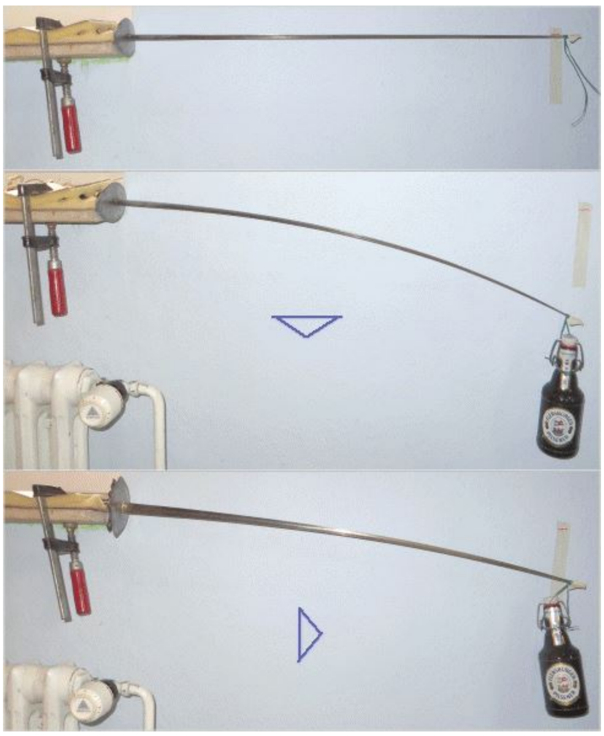
Static Properties of Swords

For starters, you could go back to chapter 3 where I introduced the definition of major *static* material properties and how they are measured. Properties like Young's modulus or hardness emerged, and we will need that here. But now we are looking at static properties of a sword, and not just a homogeneous material. What we do, in essence, is to put a static or fixed load on a sword at rest all the time and consider how it responds. Look at the picture below to get an idea of what that could mean.
We already know that we can get three fundamental results:

1. The sword deforms elastically. After removing the load it resumes its old shape
2. The sword deforms plastically. After removing the load it remains permanently bend.
3. The sword fractures.

We will only consider the first case for starters.

- "**Static load**" in the most simple version means that you fix your sword at some "point" to something unmovable and then apply forces somewhere. One example of how to do this is shown below.



Basic sword bending experiment. Unloaded (top) and loaded in different directions relative to the blade cross section
Source: Photographed Feb. 2018

- A smallsword with a triangular blade was used, the hilt was fixed to a window sill. A (full) beer bottle provides for a defined force near the tip of the blade. The sword bends quite a bit but differently if loaded at right angles to the long side of the triangle defining the blades cross-section (middle picture), or parallel to it (lower picture). I would guess that nobody is going to be very surprised about the outcome of this experiment. You have a "feeling" for the kind of curvatures you get in this case. You also could predict that outcome if I would have used a more substantial sword, for example a katana: There wouldn't be any noticeable bending.
  But that's it. If I now would ask you to *calculate* the exact curve that the sword assumes, you will not be able to comply (with some 99.999 % probability). Few are the people who know how to calculate a "bend beam".

Let's generalize a bit. For assessing static properties, we need to first immobilize at least one point of our sword in order to make sure that it cannot move around or rotate. All it can do is to bend (including plastic deformation and fracture) if you now apply forces - all kind of forces - on the "free" parts. Under the influence of the forces your sword will assume some bend shape, and as long as the forces hold, nothing changes anymore. That's what static means: Nothing changes.
You might, however, slowly increase the magnitude of the forces and watch what happens.

- One way of doing that would be the good old tensile test - clamp it and pull. You would not produce a large effect, however, with a real swords and forces applied by humans. This is not necessarily true for the reverse, compressive testing; I will get to this.
  The natural way to go at it *for starters* is to immobilize the hilt and than apply a force at a right angle to the blade near the tip - as shown above.

We will deal with static properties in the next sub-chapter. I will look at:

1. How do parameters of your sword influence how much it bends? That necessitates to consider the basic "beam-bending" experiment as shown above a bit more closely.
2. How do parameters of your sword influence "buckling", the shape-change if you *push* straight and at a right angle at an immobile hard object?
3. What can we say about bending and fracture of a sword (and not just a material)?
4. How do different sword types compare - wootz, pattern-welding, katana, uniform steel, and so on? More precisely: what kind of advantage - if any - do these materials / forging techniques offer?
5. Sharpness and retaining it. That's a static property, too. What has Materials Science to say about that?

Doing that without equations is quite a challenge. Far more challenging, however, is what comes next: dynamic properties.

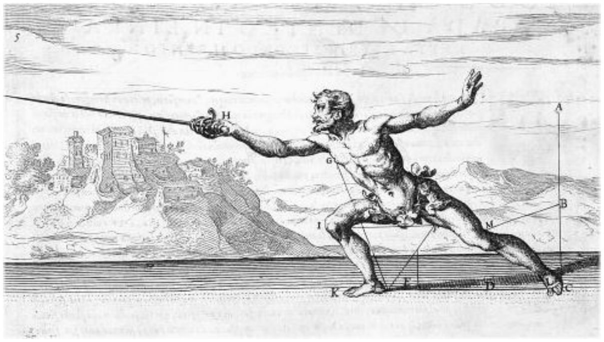
Dynamic Properties of Swords

It may come as a surprise that you can look at dynamic properties while your sword is still (partially) immobilized because the hilt is clamped to an immovable object. The blade, however, can still vibrate. In the simplest way, the tip moves back and forth with some frequency, in the not-so-simple version a more complex "vibration mode" might occur. This is seen as a dynamic property, however.
A quick look at the physics of vibrating sword blades will teach you one thing: Forget it! Calculating anything is rather involved. I will look at vibrations at the end of the next sub-chapter; so let's go for other dynamical properties first.

Dynamical properties emerge as soon as you move your sword. We are going at that in three steps:

1. The sword is moved by forces applied by massless ghosts. In other words, we just look at the basics physics of moving an object with a longish shape.
2. The sword is moved by you. Unfortunately you are not massless. And you never just move your sword, but in doing so you always move some part of yourself too. So we have a combined system: a well defined hard object with a fixed and not too complex geometry that is loosely connected to an ill-defined slimebag with changeable geometry.
3. The sword is moved by you *and* actually hits something. All three entities experience forces acting on then: the target, the sword, and you (mostly your hands and arms).

This is going to be complicated, make no bones about it! Looking just at the first point, we will first consider straight motions or translations without rotating the sword. An example could be an ideal thrust as illustrated below (note the ghost)!



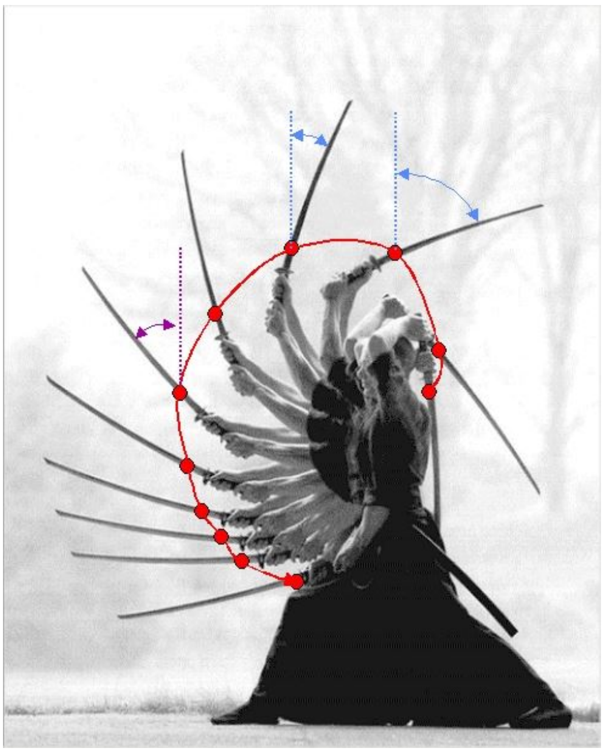
Moving your sword

Source: Net; from a 1610 book about fencing wreitten by one Capo Ferro

- But moving your sword without rotating it is certainly not what you do most of the time. Whatever you do, the total movement of the sword can best be described by looking separately at the two ingredients of that movement:

  1. The movement of the center of gravity of the *sword* along some line in space.
  2. The rotation of the *sword* while moving along.

  Look at the picture below to get an idea of what I mean. The ghost of a samurai is at work here. The red line describes the path of the center of gravity of the sword. The three angles indicated give an idea of the rotation of the sword relative to a vertical l line at the points in question. Note that the sign of the angle changes, this is indicated by different colors.



Moving your sword

Source: Internet at large

- With ghosts at work, this is still easy to grasp.
  Now let's replace the massless but powerful ghost by you. At any point in time during the swing you need to exert specific forces and torques to the sword hilt in order to produce that movement. You do that with your hands but they are attached to the rest of the body by arms and so on. In making the sword move in a certain way, you move your hands, your arms and other parts of your body. To do that, you need to exert proper forces and torques to various parts of your body. And you feel forces and torques in your hands, mostly, but also in other parts of you body.
  If you try to make the movement shown above with different swords or with a battle axe, you need to apply different forces and torques, and you will experience quite different feelings, too. With some swords you may not even be able to make the desired movement, or at least not very fast.

The forces and torques you experience by "body feel" thus are always a combination of what it takes to move and rotate the swords plus what it takes to move your body parts. When you swing your old and familiar sword you are so used to it that your body exertions don't register much. When you test a new sword by swinging it around, getting a feeling for its "speed" and so on (see above), you notice the *differences* in what your body now has to do relative to what it's used to. In particular you notice possible limits you might encounter. If, let's say, a swift rotation of 90^{o} takes and effort of 90 with your familiar sword, with your limit at 100, than a sword that would need a 110 seems "unmovable" to you. In physical reality the new sword takes only about 20 % more effort for the move difficulty but for your feeling the difference is much larger. That's why swords that are not all that different from a technical point of view might feel very different to you.

We now progress to the last and most complex part of sword dynamics: We hit something! Three basic questions come up in this context:

1. What happens to the object we hit? Think in terms of transferring force, momentum, energy, and how that impacts the object. What do these parameters mean to the object hit?
2. What happens to your sword? What kind of deformation will it experience? Will it start to vibrate and if so, how?
3. What "feeling" is transmitted to your body? What do I feel, upon impact, in the hand holding the sword? The arm? The whole body? How does that depend on the sword properties or on the position on the blade that actually hits the target?

The first thing to note about this is

Tackling this needs rather involved physics
It's rather complicated!

- I'll do my best but don't get your hopes up too much. You will have to put up some effort too.

At this point it is time to introduce the major contributions that you can find in the Net (or with the links given below and elsewhere) for sword properties in general and for dynamic properties in particular.

1. **George L. Turner**:Dynamics of Hand-Held Impact Weapons [2].
George Turner's work is rather amazing if not all that easy to read. It is actually a 150 page book with plenty of equations. I would vote for awarding him a German Ehrendoktor", a Ph.D "honoris causa", for this work. I learned much from it and used it throughout of what follows.
2. **Vincen Le Chevalier** has published several outstanding "papers" in the Net; some you cna access from here [3].
He also offers a "Weapon Dynamics Computer" in the Net, a tool designed to compute and document the dynamic properties of swords and other hand-held weapons. You can access it through Vincent's homepage. Peter collaborated here with Peter Johnsson (see below) who provided design insights and precious sword data, during the preparation of the exhibition 'The Sword – Form & Thought'" [4].
3. **Peter Johnsson**, sword maker, contributed to the "The Sword - Form and Thought" book [4] that documented a special exhibition (Sept 2015 - Fbe. 2016) in at the "Deutsches Klingenmuseum" in Solingen, Germany.
Peter supplied fetching graphics that relate to a special geometrical analysis of the swords shown in the exhibition, and the result of the calculations done for most of these words by Le Chevaliers with his computer program.

The first two authors found it impossible to explain major dynamical properties of swords without resorting to equations (and, of course, assuming that the reader has some working knowledge of physics and math). I tend to agree with their point of view but are nevertheless sticking to my ~~guns~~ sword: no equations!
Since there is no such thing as a free lunch, you will get a lot of words instead.

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[1] John **Clements**: "Longsword and Katana Considered", The Association for Renaissance Martial Arts (ARMA), Internet Essay (1999).
John has some experience in using a sword (in sports only), in contrast to me, and seems to know what he writes about.

[2] George L **Turner**: Dynamics of Hand-Held Impact Weapons, Sive De Motu, Association of Renaissance Martial Arts (2002) posted on the pages of "ARMA - the Association for Renaissance Martial Arts". The book can be directly accessed here

[3] Vincent Le Chevalier; selected papers, all accessible via his home page: or directly if links are given below:

1. "A dynamic method for weighing swords" November 15, 2014.
   The title is a perhaps a bit unfortunate because the article describes much more than "weighing" your sword. In essence, it discusses the important parameters of a sword, how to obtain them experimentally, and how they connect mathematically (lots of equations in the appendix). It also introduces the "two masses on a stick" model for simulating dynamics. It helps you to find the parameters of your sword that you need to supply for the:
2. On-Line weapons dynamics computer. You have to find it in the Net, the link may help.
3. Modelling impacts and damage. The article does exactly what the title says. If does so with equations on just a few pages.
4. Simulating Sword Properties. Explaining how the simulation program works and in particular some information about vibration modes computation.

1.

[4] "Das Schwert - Gestalt und Gedanke ("The Sword - Form and Thought"). Hrg.: Barbara Grotkamp-Schepers et al. The book to a special exhibition at the "Deutsches Klingenmuseum Solingen", Sept. 2015 - Feb. 2016.